Evaluating Long Term Water Quality Data Sets

H. Block and D. Gregor (1)

ABSTRACT

The Water Quality Branch (WQB), Environment Canada, maintains long term water quality sampling networks in the three prairie provinces of Western Canada. To interpret the data from such a program, it is necessary to fully appreciate the complexities of the data base. In a case study, data collected between 1964 and 1979 in a subalpline basin in Alberta for the purpose of assessing the effects of forest clear cutting on surface water quality were evaluated. The authors found that the data are subject to a series of external biases which significantly affect the interpretability of these data. These external biases include: changes to the location of the laboratory analysing the samples, varying analytical methods, varying analytical detection limits, and varying sampling frequencies. These factors, coupled with annual variations in the hydrologic regime, must be considered when interpreting the data to avoid misinterpretation of trends or causality.

(1) Water Quality Branch
Western and Northern Region
Environment Canada

EVALUATION A LONG TERME DES DONNEES DE LA QUALITE DES EAUX

H. Block and D. Gregor (1)

ABSTRACT

La Direction de la qualité des eaux, d'Environnement Canada, maintient des réseaux d'échantillonnage à long terme dans les trois provinces des Prairies de l'Ouest canadien. Pour interpréter les données d'un tel programme, il est nécessaire de bien saisir toutes les complexités de la base de données. Dans une étude représentative, on a examiné les données recueillies entre 1964 et 1979 dans un bassin subalpin en Alberta afin d'évaluer les effets de la coupe à blanc sur la qualité des eaux de surface. Selon les auteurs, les données sont influencées par de multiples facteurs externes qui en modifient largement l'interprétation. Ces facteurs incluent: les changements de laboratoire d'analyses, de méthodes analytiques, de limites de détection et de fréquences d'échantillonnage. Tous ces facteurs, associées aux variations annuelles du régime hydrologique, doivent être pris en considération pour empêcher que les tendances ou les causes soient mal interprétées.

EVALUATING LONG TERM WATER QUALITY DATA SETS

INTRODUCTION

Water quality measurement and assessment activities have been undertaken by environmental agencies on an ongoing basis for 20 years or more. The Water Quality (Branch) of Environment Canada in cooperation with the provinces has been a key agency in collecting, and storing the data from these long term programs as well as making these data available through publications and a computerized data bank. Currently, the Branch is evaluating its data and in turn its programs to meet the needs of the Branch, resource managers and other users. One case study undertaken as part of this evaluation employed data collected over a period of 15 years for the purpose of assessing the effects of forest clear cutting. Findings of this study serve to illustrate the need to understand the complexities and intrinsic characteristics of the data base before applying statistical procedures to draw conclusions about trends. Without this essential first step, the conclusions could be spurious, simply reflecting biases in the data and not a true cause-effect relationship. This work has been undertaken in conjunction with a major interpretive review of the data from the Marmot Creek Basin (Block, H.A and Gregor,D.J., 1984).

STUDY BACKGROUND

The results for the case study are from the Marmot Creek basin. This basin is located approximately 70 km west of Calgary in the eastern Rocky Mountains (Figure 1). The basin was established as an experimental watershed in 1962 to determine the effects of land use on the hydrology and related characteristics of the Basin.

The Marmot Creek basin, with an area of 940 ha, is typical of the spruce fir forests found along the eastern slopes of the Rocky Mountains. The Basin contains three sub-basins: Cabin Creek with an area of 236 ha, Middle Fork Creek with an area of 285 ha and Twin Creek with an area of 264 ha.

The collection of water quality data began in the fall of 1963 and continued to January 1979. In total, five sampling sites were selected, one each near the mouth of Cabin, Middle Fork and Twin Creek, Middle Fork Creek at the cirque and Marmot Creek near the mouth (Figure 2).

Following the initial phase of the study in which "baseline" water quality conditions were documented, the forest cover in two of the sub-basins (Cabin and Twin) was manipulated. Middle Fork Creek was intended to serve as a control watershed in which no forest cover was removed.

Cabin Creek was the first of the two sub-basins within the Marmot Creek Basin to be manipulated. During the fall of 1971, 2.89 km of new roads were constructed and 4.04 km of existing roads were upgraded in preparation for timber harvest. The total area used or disturbed by roads was 8.9 ha or 3.4% of the total watershed area. Logging occurred during the period July to September 1974 when 6 blocks ranging in size from 8 to 13 ha were cleared. The total area of the six blocks was 53 ha which represents approximately 20% of the total watershed area or 50% of the spruce-fir forested area. The logs from the cut blocks were skidded downslope by rubber tired skidders and crawler tractors. (Rothwell, 1977)

The main cut in Twin Creek sub-basin was carried out in 1978 (after the freshet) and during 1979. Thus the termination of the sampling program in January, 1979 precluded any assessment of the effects of the clearcutting in Twin Creek sub-basin. Instead, the Twin Creek data, with the last 10 samples excluded, served as a second control watershed during this case study.

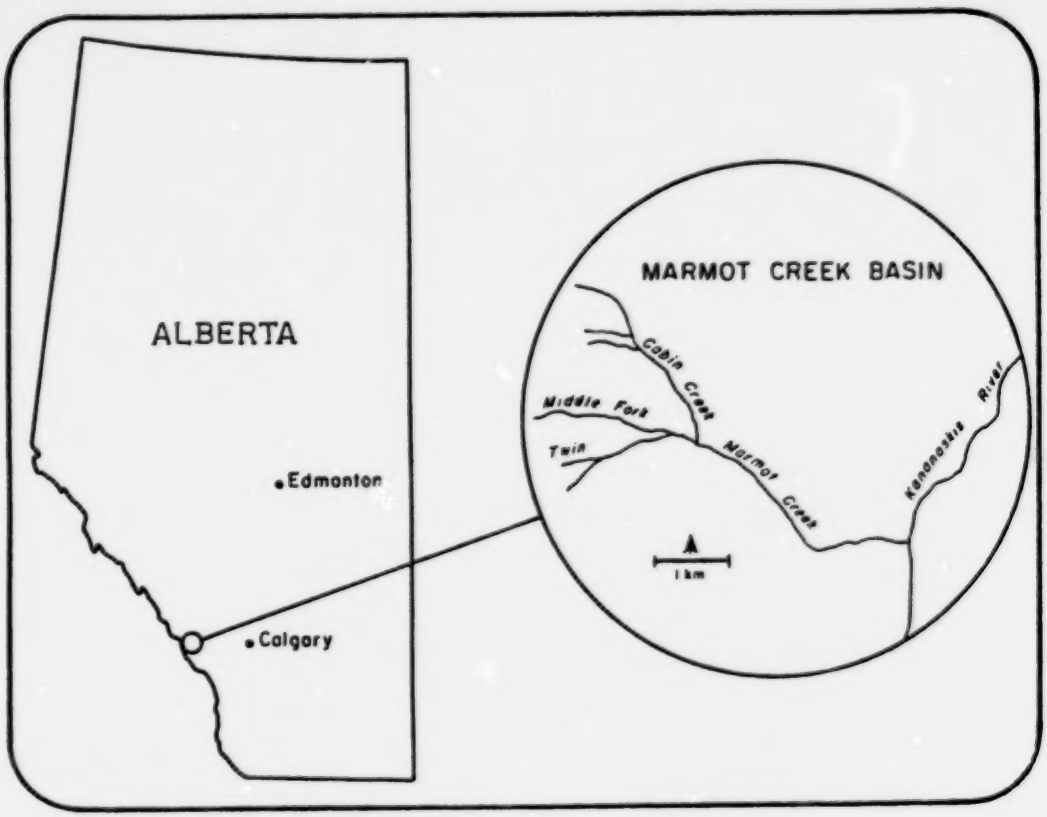
In the course of the study, the frequency of sampling varied from a low of 12 samples per year to more than 100 per year (Table 1). During most years of the study, particularly 1972 to 1978, samples were collected at irregular intervals. Generally, samples were collected during the period mid-May to mid-July, corresponding to the period when flows were highest.

During the years 1963 to 1967, the samples were analysed at a laboratory in Ottawa. Following the establishment of a regional Branch laboratory in Calgary during the fall of 1967, samples were analysed there. During the course of the study, the analytical methods and parameters measured were changed. Generally, the samples were analysed for major ions (calcium, magnesium, sodium, potassium, chlorides, sulfates, alkalinity, silica), nutrients (one or more forms of nitrogen, phosphorus and carbon), physical parameters (conductance, temperature, pH, colour, turbidity), and metals (iron, manganese, copper, lead, zinc as dissolved and/or extractable forms).

EVALUATION OF RESULTS

During the review of the data, four major factors which

Figure 1 Marmot Research Basin



must be taken into account in the interpretation of the data were identified. These factors are:

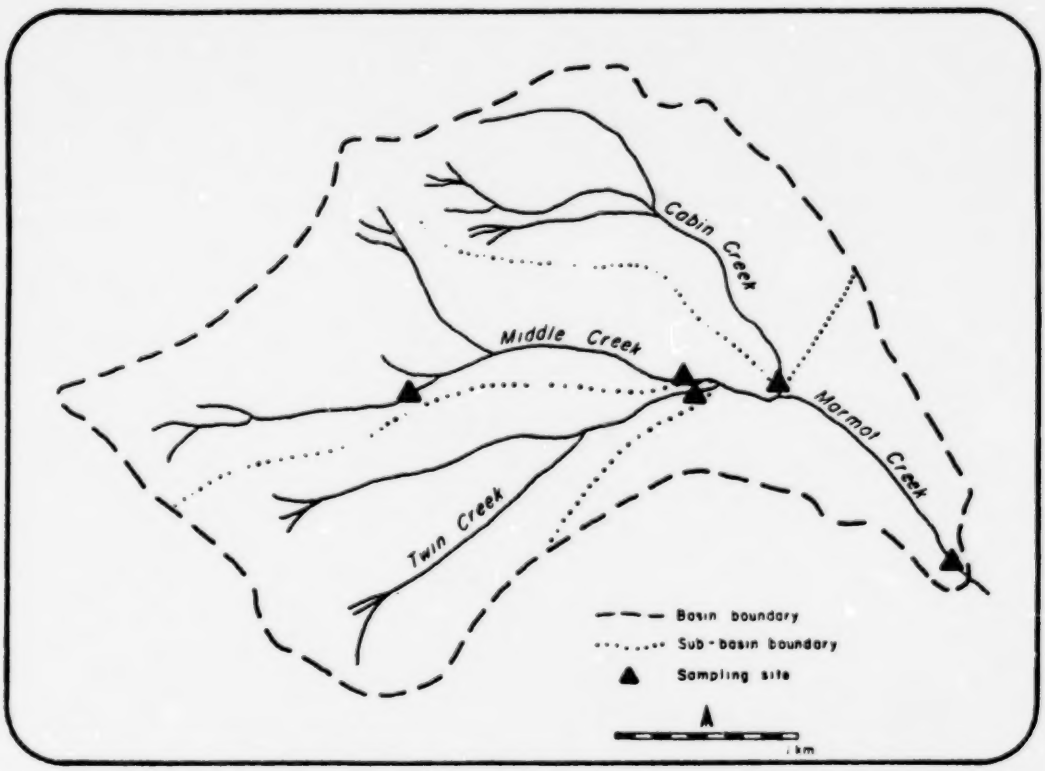
a) changing laboratories;
b) changing analytical methods;
c) changing the timing and frequency of sampling; and
d) changing the analytical detection limits.

Each of these are discussed in more detail for selected water quality parameters which most clearly illustrate the biases. Although these factors are considered individually, it should be noted that in actual fact, the biases operated interdependently.

a) Implications of Changing Laboratories

At first glance, the time series for pH in Cabin Creek (Figure 3) suggested that pH increased during the study

Figure 2 Sampling Sites in Marmot Basin



period. This trend appears as a step intervention (Figure 4) where annual mean values for Cabin Creek and Middle Fork Creek are presented. Note, however, that samples collected prior to October 1967 were analysed in the Ottawa laboratory while subsequent samples were analysed at the Calgary laboratory. The marked increase in pH values after 1967 is attributed to the change in the location of the laboratory. This change decreased the time samples were in storage prior to analysis. In the absence of data from the control watershed together with the knowledge that the location of analyses changed, one may have falsely concluded that an intervention had occurred. Unfortunately, there was no period of overlap where samples were analysed at both laboratories to permit a direct comparison between the two laboratories.

Other parameters were likely affected by the laboratory change. For example, the annual mean concentrations of NO_3 + NO_2 in both control watersheds show large increases coincident with the change of location of analyses (Figure 5). These apparent trends must be assessed further relative to the effect of other biasing factors.

Table 1 Number of Samples Collected in Marmot Basin

Year	Marmot Ck	Cabin Ck	Twin Ck	Middle Ck	Middle Ck B Unique	Total
.963	0	0	0	.	17	.0
.964	3	34	34	33	39	140
.965	0	29	37	37	26	.29
.966	32	34	34	28	.8	.66
.967	75	42	42	38	19	2.5
.968	32	32	32	32	33	333
.969	21	.8	.7	18	..	85
.970	.2	.2	.2	.2	.0	10
.971	.2	.3	.2	.2	1	59
.972	....	...2	...0	..11	1	450
.973	49	48	46	47	.0	200
.974	38	37	37	37	0	.55
.975	36	44	36	36	7	.53
.976	38	38	36	37	3	.54
.977	35	35	35	35	9	.48
.978	39	39	39	39	.	.56
.979	1	.	.	.	0	4
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	67.	597	580	575	3.4	3527

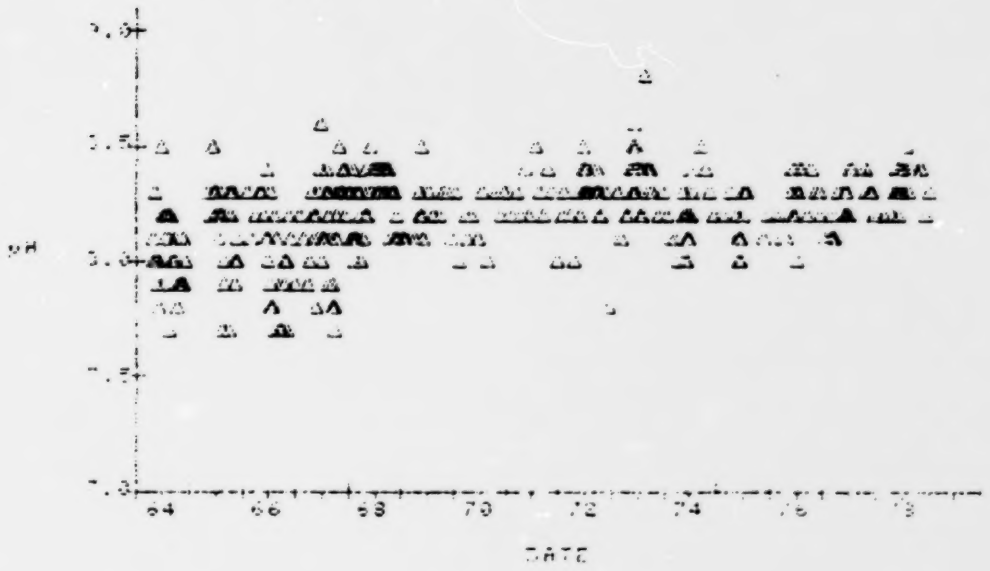
(b) Implications of Changing Analytical Methods

Three directly related points are noteworthy in Figure 5. First, reference to the 12 individual values for 1970 for Twin Fork Creek shows that the high mean value (0.99 mg/L) for NO_3 + NO_2 is due to a single anomalous value (0.75 mg/L) in the dataset. This single value causes a two-fold increase in the mean value which would otherwise be reported.

The second point warranting attention is the large increase in NO_3 + NO_2 concentrations in Cabin Creek in 1978. This increase is not associated with a comparable increase in either of the control watersheds. Reference to the individual data indicates that the mean value of 0.098 mg/L adequately reflects the concentration during 1978 as most values were in the range 0.07 to 0.13 mg/L.

The third point to be noted in Figure 5 is that the annual mean concentrations of NO_3 + NO_2 generally increased

Figure 3 Cabin Creek Time Series for pH



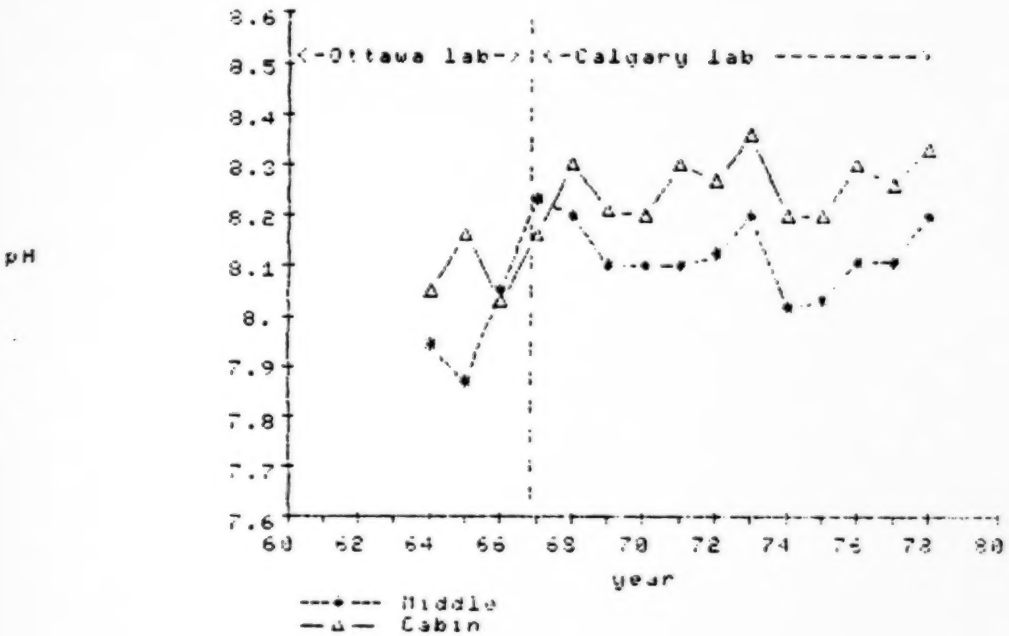
between 1971 and 1974. The timing of this increase corresponds to the period of road construction (fall of 1971) and clearcutting (July to September, 1974).

However, two other factors; specifically, changing analytical methods and variable timing and frequency of the sampling program must be taken into consideration before arriving at a conclusion regarding trends. The latter factor will be discussed in the following section.

The apparent increase in the annual mean concentration of NO_3 + NO_2 after 1972 (noted above) for Cabin Creek is also evident in Figure 6 where individual concentrations are plotted against time. Figure 6 suggests that the concentrations of NO_3 + NO_2 in Cabin Creek appears to increase after May 1972. However, since a similar trend is apparent in the NO_3 + NO_2 levels in each of the control watersheds (Figures 7 and 8) the increased concentrations are not likely to be a reflection of the road construction and clearcutting within Cabin Creek.

NO_3 + NO_2 was analyzed by three different analytical methods during the study. The majority of the samples

Figure 4 Annual Means for pH



collected prior to 1972 were analysed by method 07105L* whereas samples collected during the period June 1972 to September 1976 were analysed by method 07106L* while the remaining samples were analysed by method 07110L*. Unfortunately, there was no overlap where samples were analysed by both methods which would have permitted a direct comparison of the methods. The apparent increase in concentration of NO_3 + NO_2 after May 1972 at least in part reflects differences due to analytical methods. By way of further explanation of the observed trends for NO_3 + NO_2, it must be noted that the flow regime for all three watersheds changed considerably between the period 1964 to 1971 and 1972 to 1978 (Figure 9). This uncontrollable factor obviously influences the data and clearly demonstrates the need to consider all possible factors in the interpretation of the data.

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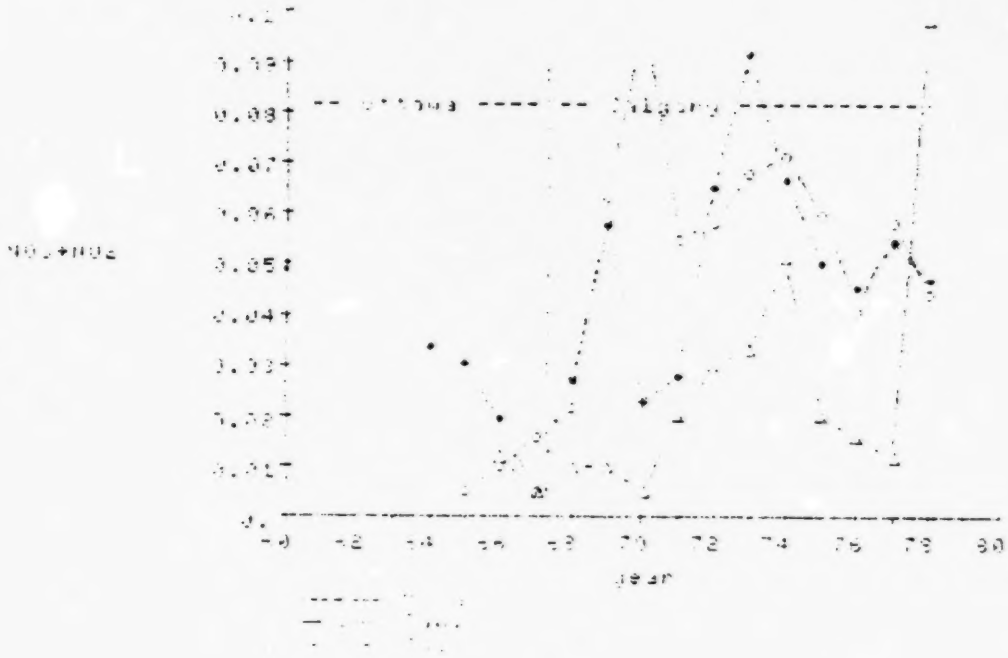
* Each method of analyses is described in the NAQUADAT Dictionary of Parameter Codes (Water Quality Branch, 1984).

Figure 5 Annual Means for Concentrations for NO_3 + NO_2

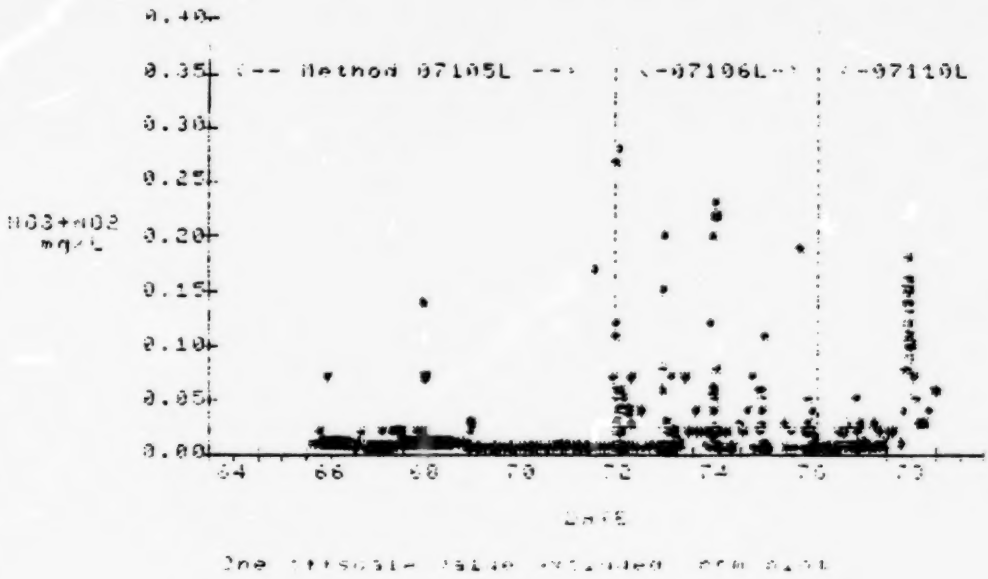


c) Implications of Changing the Timing and Frequency of Sampling

The third factor which may have an effect on the reported results is the timing and frequency of sample collection. Starting in 1972, Branch staff took a more active role in sample collection, collecting most of the samples during the summer months. The increased emphasis on the high flow period (when NO_3 + NO_2 concentrations were highest) also contributes to the apparent increase suggested in Figures 6 through 8.

The effect of changing the timing and frequency of the sampling program is better illustrated by the specific conductance data (Figure 10) which is assumed here to be a conservative variable which operates in an inverse manner to flow. In all three basins, the highest mean annual values for conductance were recorded in 1970 and 1971. In part this may be due to the low flows in both basins during these two years (Figure 9). Another factor however, is thought to be equally

Figure 6 Cabin Creek Time Series for $NO_3 + NO_2$

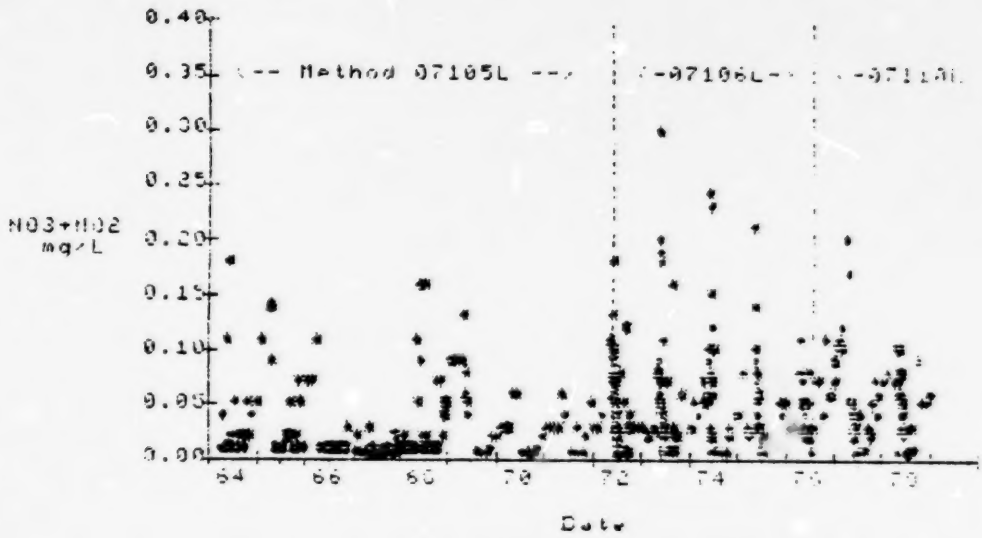


important. During each of 1970 and 1971, only a dozen samples for conductance were collected in each of the sub-basins. Of these, only two were collected in each basin during the high flow period. This is in sharp contrast to other years when the majority of the samples were collected during the high flow period when conductance values would be the lowest. Hence the variability in the sampling frequency and the timing of the sample collection appear to bias the annual mean value. Because of this bias, meaningful trend analysis of the annual mean values is not feasible.

d) Implications of Changing Analytical Detection Limits

Another factor which must be considered when interpreting these water quality data is the effect of changing analytical detection limits. The plot of annual mean concentrations of TP (Figure 11) is used to illustrate the point. At first glance, this plot suggests that the concentration of TP in Cabin Creek declined during the course of the study. This may be due to the bias introduced into the data by a change to the analytical detection limit for TP. Samples prior to 1968 were analysed in the Ottawa laboratory which reported a detection limit of 0.02 mg/L whereas subsequent samples were analysed in the Calgary laboratory which reported a detection limit of 0.003 mg/L.

Figure 7 Middle-Fork Creek Time Series for $NO_3 + NO_2$



Note that values reported as being below the analytical detection limit (L0.02 mg/L for example) were interpreted as being one-half the numeric value of the detection limit and were plotted accordingly (0.02/2 = 0.01). The plotted value for TP, when TP concentrations were less than the reported detection limit for the method in use at the time, therefore, decreased from 0.01 to 0.0015 mg/L. This decreased detection limit has a major impact upon the trend portrayed.

Figure 8 Twin Creek Time Series for $NO_3 + NO_2$

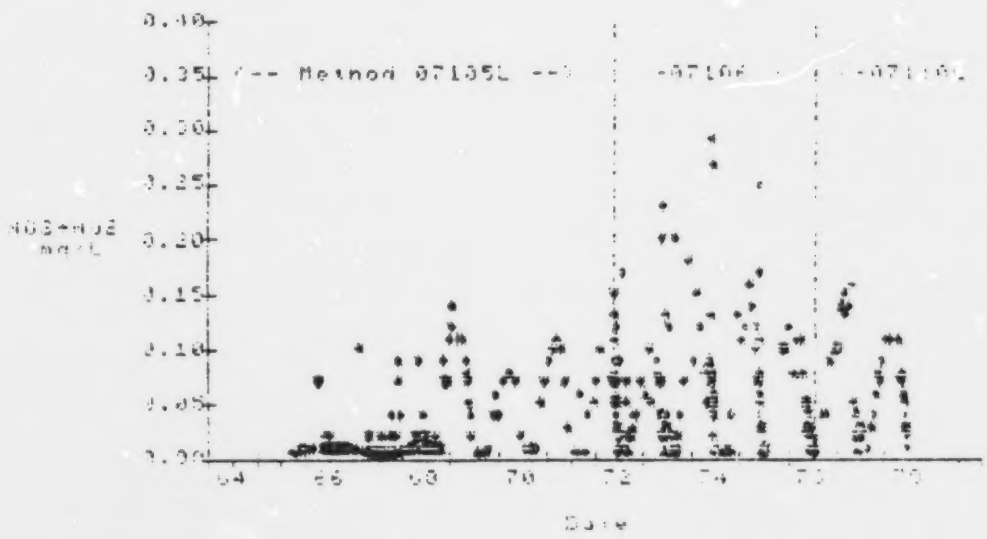


Figure 9 Annual Mean Discharge

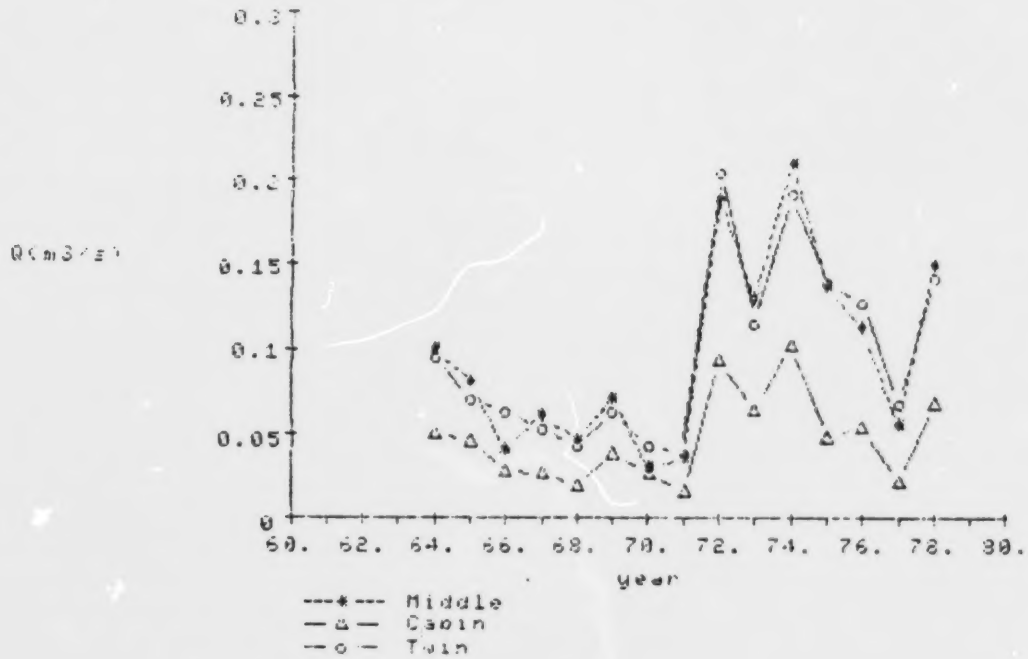


Figure 10 Annual Mean Values for Conductance

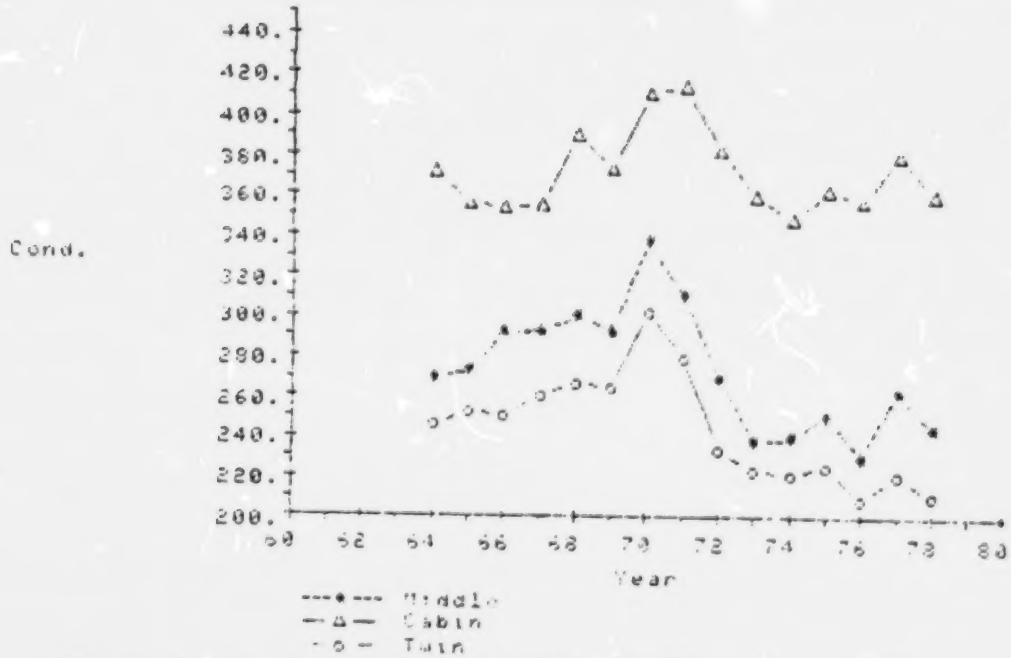
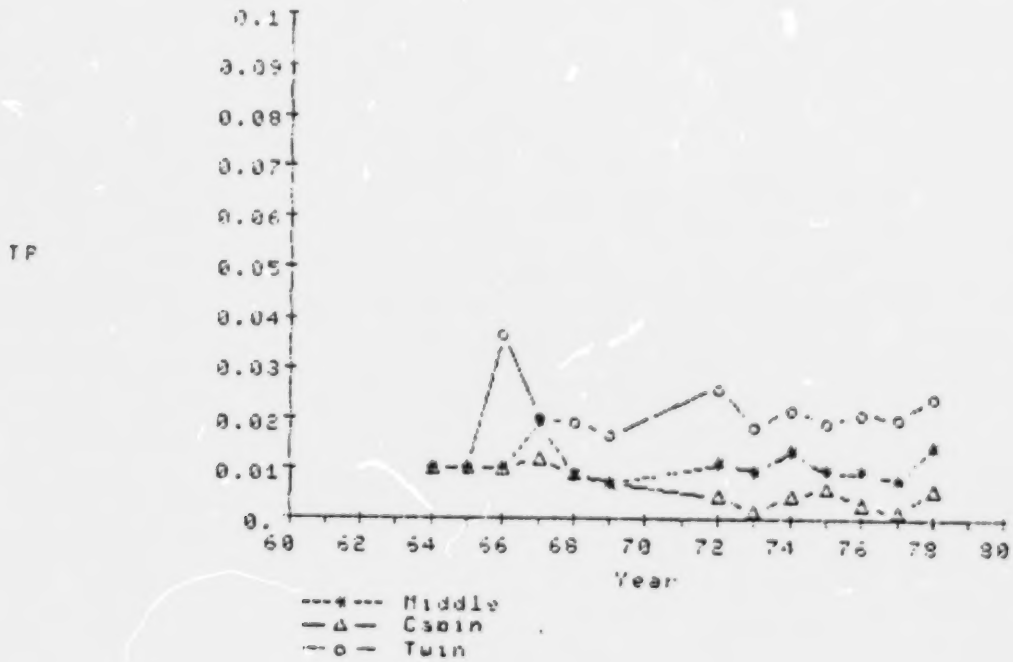


Figure 11 Annual Mean Concentrations for TP



SUMMARY AND CONCLUSIONS

It is readily apparent that a number of biases may exist in a long term water quality data set which make it difficult to interpret. In this study, the change in the location of the laboratory (which introduced changes to the shipping and storage procedures for the samples), the changes in the analytical methods, the changes to the analytical detection limits, the variability in the sampling frequency and the timing of sample collection each were found to introduce bias. These factors coupled with annual variations in the hydrologic regime had to be considered when interpreting the data for the purpose of determining the effect of forest clearcutting on water quality in order to minimize the probability of misinterpretation of trends or causality. These problems are not uncommon in long term water quality data bases and users are encouraged to invest the time to assess the data for similar systematic biases prior to proceeding with the interpretation. Similarly, before changing laboratories or analytical methods, program managers are encouraged to ensure that a period of overlap exists so that the effect of each change can be measured directly.

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